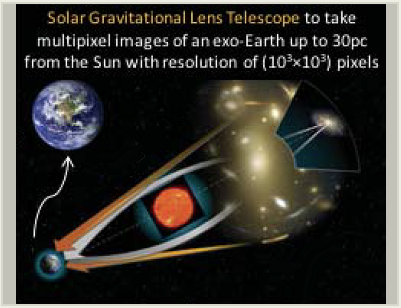
NASA Innovative Advanced Concepts

Direct Multipixel Imaging and Spectroscopy of an exoplanet with a Solar Gravity Lens Mission

Completed Technology Project (2017 - 2018)

Project Introduction

We propose to build upon our Phase I study of a mission to the regions outside our solar system, with the objective of conducting direct high-resolution imaging and spectroscopy of a habitable exoplanet by exploiting optical properties of the solar gravitational lens (SGL). A mission to the focal area of the SGL (which lies beyond 548.7 astronomical unites (AU) on the line connecting the center of the exoplanet and that of our Sun, called the focal line of the SGL) carrying a modest telescope and coronagraph could deliver direct megapixel imaging and high-resolution spectroscopy of a habitable Earth-like exoplanet orbiting a host star at a distance of up to 30 parsec. The remarkable optical properties of the SGL include major brightness amplification (~1e11 at \\lambda=1 um) and extreme angular resolution (~1e-10 arcsec) in a narrow field of view. The entire image of such an exo-Earth is compressed by the SGL into an instantaneous cylinder with a diameter of ~1.3 km in the vicinity of the focal line. Moving outwards while staying within the image, the telescope will take photometric data of the Einstein ring around the Sun formed by the light from the exoplanet and will process the data to reconstruct the image of the exoplanet with a few km-scale resolution of its surface, enough to see its surface features and signs of habitability. Under a Phase I NIAC program, we evaluated the feasibility of the SGL-based technique for direct imaging and spectroscopy of an exoplanet and, while several practical constraints have been identified, we have not identified any fundamental limitations. We determined that the foundational technology already exists and has high TRL in space missions and applications. Furthermore, the measurements required to demonstrate the feasibility of remote sensing with the SGL are complementary to rotational tomography measurements and ongoing microlensing investigations, so our effort would provide high-value scientific information to other active astrophysics programs. Under the Phase II program, we will continue to advance our understanding of the SGL-based imaging and spectroscopy, improve on the computational methods developed in Phase I, evaluate specific hardware implementations, and ultimately produce a roadmap for the direct high-resolution sensing of exoplanets. We will refine our understanding of mission architectures and the technology roadmap. To that extent, we will refine the Phase I mission concepts: i) a single probe-class spacecraft, ii) a swarm of small and capable spacecraft, iii) a "string-of-pearls" mission concept using multiple sets of moderate size spacecraft, and will consider other concepts, if identified. Our main objective for this effort is to study i) how a space mission to the focal region of the SGL may be used to obtain high-resolution direct imaging and spectroscopy of an exoplanet by detecting, tracking, and studying the Einstein ring around the Sun, and ii) how such information could be used to detect signs of life on another planet. We will deliver a list of recommendations on the mission architectures with risk and return trade offs and discuss an enabling technology development program. The resulting mission concept could allow exploration of exoplanets relying on the SGL capabilities decades, if not centuries, earlier than possible with other extant



Direct Multipixel Imaging and Spectroscopy of an exoplanet with a Solar Gravity Lens Mission. Credits: Slava Turyshev

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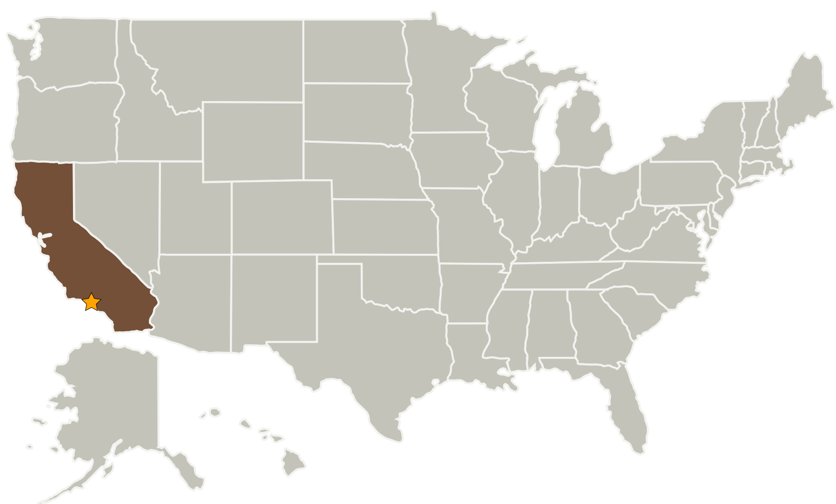
technologies. Phase II will provide us with a clear understanding of the scientific value of the mission and the trades needed to define the most cost-effective mission design and architecture. If no showstoppers will be identified, we will have all the needed tools and mission rationale to present the SGL imaging mission to the science community for a broader support. As the concept may be the only way to view a potentially habitable exoplanet in detail, it would generate the public interest and enthusiasm that could motivate the needed government and private funding.

Anticipated Benefits

We propose to study a mission to the deep regions outside the solar system that will exploit the remarkable optical properties of the Solar Gravitational Lens (SGL) focus to effectively build an astronomical telescope capable of direct megapixel high-resolution imaging and spectroscopy of a potentially habitable exoplanet.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★Jet Propulsion Laboratory(JPL)	Lead Organization	NASA Center	Pasadena, California

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Center / Facility:

Jet Propulsion Laboratory (JPL)

Responsible Program:

NASA Innovative Advanced Concepts

Project Management

Program Director:

Jason E Derleth

Program Manager:

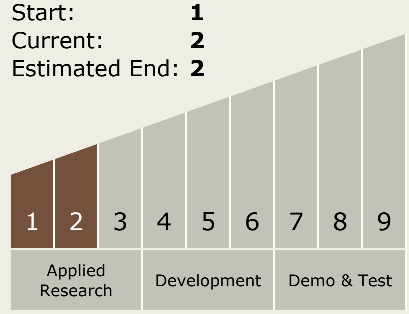
Eric A Eberly

Principal Investigator:

Slava G Turyshev

Technology Maturity (TRL)

Start: **1**
Current: **2**
Estimated End: **2**



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Completed Technology Project (2017 - 2018)

Primary U.S. Work Locations
California

Project Transitions

April 2017: Project Start

Technology Areas

Primary:

- TX11 Software, Modeling, Simulation, and Information Processing
  - └ TX11.5 Mission Architecture, Systems Analysis and Concept Development
    - └ TX11.5.2 Tools and Methodologies for Performing Systems Analysis

Target Destination

Outside the Solar System

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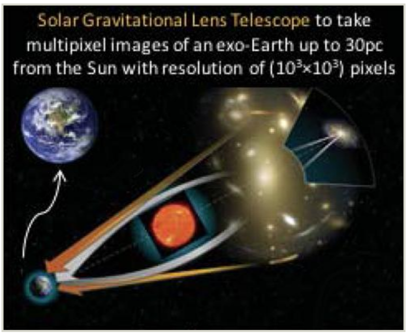
January 2018: Closed out

Closeout Summary: The remarkable optical properties of the solar gravitational lens (SGL) include major brightness ampli fication (~1011 at l=1 μm) and extreme angular resolution (~10-10 arcsec) in a narrow field of view (FOV). Such an instru ment could benefit many areas of astrophysics involving exoplanets, star formation, nebula, accretion disks, neutron stars, galactic center, etc. Here we focus only on remote investigations of exoplanets. A mission to the SGL carrying a modest tele scope and coronagraph opens up a possibility for direct megapixel imaging and high-resolution spectroscopy of a habitable Earth-like exoplanet at a distance of up to 100 light years. The entire image of such a planet is compressed by the SGL into a region with a diameter of ~1.3 km in the vicinity of the focal line. The telescope, acting as a single pixel detector while tra versing this region, can build an image of the exoplanet with kilometer-scale resolution of its surface, enough to see its surf ace features and signs of habitability. Although theoretically feasible, the engineering aspects of building and operating suc h an astronomical telescope on the large scales involved were not previously addressed. This unique concept requires serio us consideration. We report here on the results of our initial study of a mission to the deep outer regions of our solar syste m, with the primary mission objective of conducting direct megapixel high-resolution imaging and spectroscopy of a potenti ally habitable exoplanet by exploiting the remarkable optical properties of the SGL. Our main goal was not to study how to get there (although this was also addressed), but rather, to investigate what it takes to operate spacecraft at such enormou s distances with the needed precision. Specifically, we studied i) how a space mission to the focal region of the SGL may be used to obtain high-resolution direct imaging and spectroscopy of an exoplanet by detecting, tracking, and studying the Ein stein ring around the Sun, and ii) how such information could be used to detect signs of life on another planet. We consider ed several mission concepts involving either i) a single probe class spacecraft, ii) a string-of-pearls mission concept using m ultiple sets of moderate size spacecraft, and iii) a swarm of small and capable spacecraft. Our results indicate that a missio n to the SGL with an objective of direct imaging and spectroscopy of a distant exoplanet is challenging, but possible. We co mposed a list of recommendations on the mission architectures with risk and return tradeoffs and discuss an enabling techn ology development program. Under a Phase I NIAC program, we evaluated the feasibility of the SGL-based technique for dir ect imaging and spectroscopy of an exoplanet and, while several practical constraints have been identified, we have not ide ntified any fundamental limitations. We determined that the foundational technology already exists and has high TRL in spa ce missions and applications. Furthermore, the measurements required to demonstrate the feasibility of remote sensing wit h the SGL are complementary to rotational tomography measurements and ongoing microlensing investigations, so our effo rt would provide high-value scientific information to other active astrophysics programs. Our results are encouraging as the y lead to a realistic design for a mission that will be able to image exoplanets. It could allow exploration of exoplanets relyin g on the SGL capabilities decades, if not centuries, earlier than possible with other extant technologies. The architecture an d mission concepts for a mission to the SGL, at this early stage, are promising and should be explored further.

Closeout Link: https://www.nasa.gov/directorates/spacetech/niac/2017_Phase_I_Phase_II/Solar_Gravity_Lens_Mission

Images



Project Image
Direct Multipixel Imaging and Spectroscopy of an exoplanet with a Solar Gravity Lens Mission.
Credits: Slava Turyshev
(https://techport.nasa.gov/image/102190)

Links

NASA.gov Feature Article
(https://www.nasa.gov/directorates/spacetech/niac/2017_Phase_I_Phase_II/Solar_Gravity_Lens_Mission)

Project Website:

https://www.nasa.gov/directorates/spacetech/niac/index.html#.VQb6I0jJzyE